Electrooptic Propagation

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LONG TERM GOALS

Provide a quantitative description of the electrooptical propagation environment (visible and IR) within the marine and coastal environments through models and measurements.

OBJECTIVES

The EO Propagation objectives are: 1) investigate, develop and evaluate ocean and coastal aerosol models and their effects on IR propagation, 2) investigate and develop simple, realistic models for infrared propagation near the ocean surface, and 3) develop and evaluate advanced marine radiance models that are compatible with TAWS and IRTSS, and 4) to determine the optical properties of non-spherical dust aerosols and their impact IR propagation.

APPROACH

Remote (surface-based and satellite) and in-situ (surface and airborne) sensors are to be used to measure the optical and meteorological parameters from which models of aerosol-size distributions and sky/sea/terrain backgrounds can be developed and evaluated.

WORK COMPLETED

MARINE AEROSOL MEASUREMENTS AND MODELING

A significant portion of the worldwide rotorod data was compiled and analyzed for the final validation of ANAM (1.0) and its extension to broader applications, ANAM (2.0). This includes data from the North Sea ANAM validation campaign and the extended database from the TNO MAPTIP experiment and the rotorod data from HEXMAX. A new approach to overcoming the complexity of gathering additional empirical data to verify and extend the ANAM model was undertaken by utilizing the French and Dutch numerical model SEACLUSE. This model was operated simultaneously with ANAM for model parameterization. The results are now readied for implementation into a new version of ANAM, version 2.0.

Near ocean surface aerosols and the impact of surf were again the primary objectives for the aerosol measurements and modeling effort during this fiscal year. The EOPACE database has revealed the

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structure, the flux and the seaward advection of surf generated plumes. The data is now being exploited and synthesized into a practical generation/transport model.

SSC led the planning/execution of the measurement and aerosol modeling effort under the EOPACE umbrella (IOP #9) at Duck NC, Feb/March 1999. All of the aerosol/meteorology data for IOP#9 has been reduced and made available to all participants. The analysis of the EOPACE database for the advection of surf aerosol has resulted in the development of a simple 2-D model that describes the major features of observed advected data from a surf zone. The evolution of the internal marine boundary layer as it is advected offshore has been quantified for the Duck 99 effort.

The SSC San Diego IR propagation model (LWIR) beneath marine stratus clouds has been extended to include the MWIR wavelength band in the presence of solar multiple scattering. The model has been tested using airborne infrared measurements of the MWIR sky radiance backgrounds near the horizon. For elevation angles between 1 and 2.5 degrees, the calculated sky radiances using the model with the solar multiple scattering option of MODTRAN agreed with measurements to better than 1º C. Within 1 degree of the horizon, the calculated values over estimated the sky radiances by 2º C. This discrepancy may be related, in part, to the surface layer stability conditions which were "stable" during the comparison measurements, while the aerosol model was developed from size distribution measurements during "unstable" conditions.

A second thrust area is the development of the next generation Navy Aerosol Model. One component of the refinement will require a description of the evolution of a vertical aerosol concentration profile with particular emphasis on advection from a coastal region out to sea. A workshop was hosted to consider several different possible approaches. Possible future research directions include: 1) assessing of the effects of near-ocean-surface phenomena on the vertical gradients of marine aerosol in the atmospheric surface layer, and 2) the use of very high-resolution refractivity fields computed via fluid numerical simulations. A numerically generated refractivity field could be used as a propagation medium for an infrared propagation model and could be tested against some of the EOPACE data. This effort could result in collaboration with the Atmospheric Sciences Computational Group at Los Alamos National Laboratory.

An invited paper for the LASE2000 Conference has been completed.

<u>IR TRANSMISSION AND RADIANCE</u>

Data from the two-band 7-km range scintillation experiment across San Diego Bay has been analyzed by comparing values of C_n^2 derived directly (from single-point turbulence measurements), via the bulk method (from Monin-Obukhov similarity theory), and from optical scintillation. These data were also examined for scintillation signatures characteristic of infrared propagation. This was done with a time-frequency data analysis that used wavelet decomposition to transform the field-measured time series data. The wavelet decomposition was utilized to construct the equivalent of three band-pass filters. The low-pass component corresponded to a mean signal, and the high-pass component corresponded to the system noise. The remaining mid-pass component was used to find the signal variance, and to determine the Fresnel frequency.

The IOP#4 transmission data set has been analyzed by assessing the molecular (clear air) and near surface aerosol effects including the corresponding calculated extinction that would be expected from each. A batch FORTRAN program, "NAM6," was written to help with aerosol analysis in coastal regions. This program is based on the sixth version of the Navy Aerosol Model. The absolute error in transmission for all the EOPACE IOP field experiments was determined experimentally and will be used in the analysis of the FY99-00 EOPACE database.

An invited paper was given for the Optical Society of America. Results of the scintillation and refractive study were presented at the 22nd Annual Review Conference of Atmospheric Transmission Models at the Air Force Research Laboratory (Massachusetts).

SYSTEMS PERFORMANCE ASSESSMENT
The SeaRad model was compared to the rigorous first-principles model, IRTool, and both were compared to measured data. Additional IR scene data was collected at Duck, NC. A new model containing the additional phenomenology is near completion and will be tested and released during FY00. This new model will serve as a base model for future work in characterizing the littoral regime.

DUST AEROSOL MEASUREMENTS AND MODELING
This is a new start dust aerosol measurements and modeling program to determine the impact of dust aerosols on IR transmission. An extensive and thorough literature search, accompanied by numerous discussions involving researchers in the field, has been completed. Specific research priorities and a work plan have been completed. Plans/arrangements have been made for the "Dust Experiment to Study IR Extinction," (DESIRE), at the China Lake Naval Air Warfare Center Weapons Division, Nov/Dec 1999. Initial arrangements for a field program in conjunction with NASA researchers (PRIDE-Puerto Rico Dust Experiment) has been completed. In preparation for this field campaign, a reanalysis of dust data collected in and around the range has been completed. A manuscript describing the findings is in preparation.

A cooperative effort with NRL Monterey for integration of dust microphysics products into the NRL Aerosol Analysis and Prediction System (NAAPS) has been initiated. SPAWAR has negotiated and begun implementation of live-feed AERONET Sun Photometer data for the strategic South West and South East Asian theaters for the purpose of NAAPS initialization and validation.

RESULTS

MARINE AEROSOL MEAUREMENTS AND MODELING
ANAM (1.0) was improved, empirically validated, presented and reported at several technical symposiums.

The surf generated aerosol plume structure, the flux and the seaward advection of surf generated plumes is now documented in the EOPACE database.

Observations of profiles of large sized aerosol close to the ocean surface sometimes show increases in aerosol concentrations with height. To explain this, a 2D model was developed to simulate a "typical" surf zone. The result shows that the advection process must be taken into account to model the surf-produced aerosol.

The evolution of the internal marine boundary layer as it is advected offshore has been quantified for the Duck 99 effort. At wind speeds in excess of ~6 m/s, a clear internal boundary layer develops rapidly and exhibits a marked increase in coarse mode particle concentrations and specific humidity. At a wind speed of ~8 m/s, the sea generated aerosol requires at least 1 hour to come into equilibrium. At 12 m/s, probably twice that time will be required. Hence, an area of offshore non-equilibrium can exist for up to 60 km or more. Particle fluxes at 8 and 12 m/s wind speeds have been derived in a more direct manner than previous studies. The Dubovick inversion based on NASA Sun photometer sky radiance data does in fact adequately describe the aerosol size distribution for optical depths as low as 0.05. This means that we can use the AERONET Sun photometer data to adequately derive aerosol size distributions in clean marine environments.

IR TRANSMISSION AND RADIANCE

Comparison of the bulk, direct, and optical versions of C_n^2 resulted in the following observations. Bulk estimates agree well with scintillation in unstable conditions, but in stable conditions they are an order of magnitude too high. Furthermore, the sharp decrease in C_n^2 (predicted by the bulk method to occur at small positive values of air-sea temperature difference) was not observed in either the direct or optical data. These results suggest that ocean waves substantially modify the near-surface temperature and humidity gradients in the atmosphere.

Analysis of the 7-km scintillation data showed that it was possible to separate refractive effects from scintillation effects by using their different time dependencies. Refractive modulations to the signal occur on a relatively slow time scale (< 1 Hz), while scintillation generates a relatively high frequency (> 1 Hz) oscillation in the received signal. Furthermore, we identified a characteristic dominant frequency to the scintillation, which we called the Fresnel frequency. The basic thesis of this work has been that there are three primary quantities that are useful as characteristic propagation environment signatures: the signal mean, the signal variance, and the dominant frequency. Our results have shown that a measurement of the ambient meteorological conditions can be used to predict these three signal signatures.

Analysis of the IOP#4 transmission data produced the results shown in Figure 1. The top panel

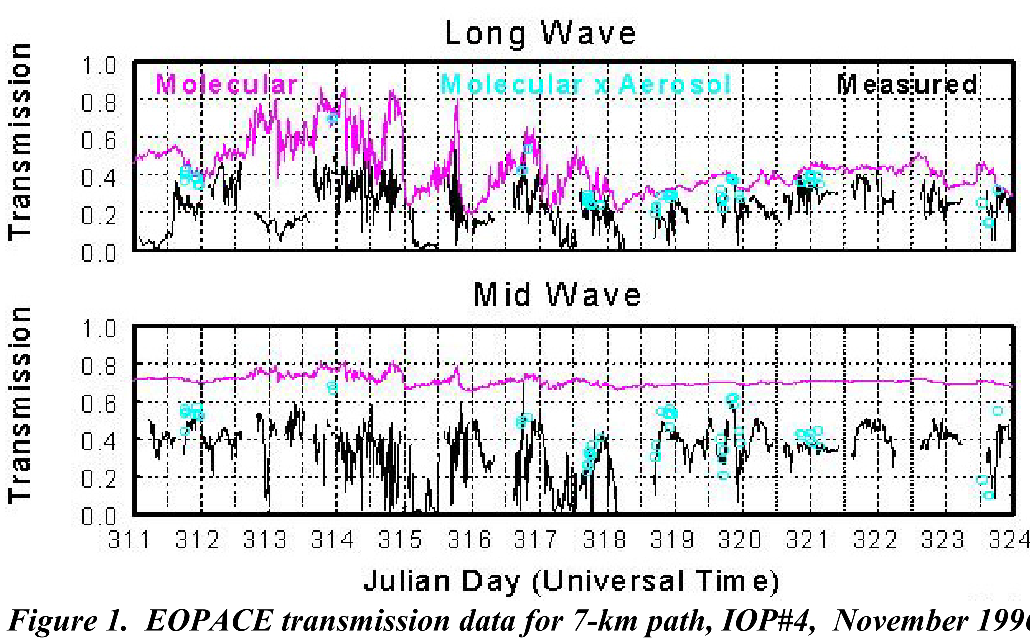

Figure 1. EOPACE transmission data for 7-km path, IOP#4, November 1996.

contains data for the LWIR band, the bottom panel the MWIR. The black line in each panel shows the transmission measured on the short (7-km) path during the 13-day period. The violet line shows the molecular (clear air) transmission estimated from MODTRAN (MODTRAN estimates were derived from meteorological conditions simultaneously observed at a mid-path buoy). The cyan circles show the product of the molecular prediction (the violet line) and the transmission due to aerosol particles by themselves (the aerosol transmission was derived by Mie theory from aerosol size distributions measured along the path).

Figure 1 makes the following points for the short path: 1) the violet line behaves quite differently in each of these panels: molecular transmission is much more variable in the long wave band than in the mid-wave band, and 2) the cyan circles, by and large, fall on top of the black line: the measured transmission is adequately explained by the joint action of molecules and aerosol particles.

<u>SYSTEMS PERFORMANCE ASSESSMENT</u>

Scene radiance values from both the SeaRad and IRTool models compared favorably with each other and with the measured data in the open-ocean cases. SeaRad represented about a three to one improvement over the original empirical water background model in TAWS. The error dropped from 13.8% to 4.6% (4.5 W/m^2/sr difference to 1.6 W/m^2/sr) in the cases studied comparing SeaRad with the empirical model. IRTool offered a slight improvement in accuracy over SeaRad along with additional capabilities including characterization of clutter and near-surface effects. However, being a rigorous first-principles model, the run time of IRTool is unsuitable for operational use. As a result, IRTool served as a starting point for a new much faster hybrid parametric and statistical model called SeaPlus.

<u>DUST AEROSOL MEASUREMENTS AND MODELING</u>

The literature search has shown that the effects of dust on EO systems performance are largely unknown. In particular, the effect of particle mineralogy and shape factors is highly contentious. The reanalysis of the dust data collected in and around NAWC China Lake has shown that the dust particles in this region have characteristics similar enough to those observed in other geographic locations to warrant further study.

IMPACT/APPLICATIONS

Rigorous physical models of background radiance and near ocean surface transmission characteristics are lacking for the marine and coastal environment. Radiance and transmission models are required to evaluate the fidelity of approximate models that may find use in operational assessment systems. This impacts directly on the performance of the universally used MODTRAN, which includes the Navy aerosol models (NAM, NOVAM). The models from this project are applicable to sensor performance assessment systems and sensor/system development projects and are directly applicable to TAWS that will be integrated into Navy NITES-2000 package. Also, the SeaPlus model relates directly to IRTSS.

TRANSITIONS

The SeaRad ocean radiance model was transitioned to NRL Monterey for inclusion into the WIN-EOTDA. Data collected in collaboration with EOPACE are shared with those investigators and are utilized by them in their projects.

RELATED PROJECTS

This project is related to NRL Monterey's mesoscale and data assimilation model projects and their program for improving the current WIN-EOTDA used by the fleet in the TESS(NC) and TAWS, the COVAMP project. This work relates directly to the TAWS and IRTSS projects as described above. Tri service coordination is conducted under the Technology Area Review and Assessment.

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